Express Mail Label No. EV 396083943 US

[0001] GRADED INDEX FIBER, ARRAY AND METHOD OF MANUFACTURE

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation in part and claims priority to PCT application PCT/US02/23751 filed July 26, 2002 and also claims priority to U.S. Patent Application 09/921,113 filed on August 1, 2001; both of which are hereby incorporated by reference herein in their entirety as if fully set forth.

[0002] BACKGROUND

[0003] The present invention relates to a graded index fiber, an array of such fibers, and more particularly, to an array of graded index fibers that are packed in a regular structure for use as a fiber optic faceplate, an image conduit or a flexible image bundle.

[0004] Graded index fibers which are used as an optical conductor are known. Typically, such optical conductors utilize a core having a high refractive index at the center which decreases as a function of the distance away from the center. One known method of fabricating a stepped graded index fiber is to utilize telescoping tubes having different indices which are placed around a central core and fused together. However, it would be desirable to have more control over the refractive index profile of a fiber.

[0005] It would also be desirable to make an array using GRIN fibers. One known reference discloses the formation of an image guide utilizing microfibers having a size of approximately 5 microns down to approximately 1 micron. The GRIN fibers are bundled together and heated to form a fused boule of solid fibers. The solid boule is then placed in a heating chamber of a drawing tower in which the lower part of the boule is continuously heated and drawn down to a uniform diameter multi-microfiber image guide. The GRIN fibers may be formed from glass or a polymeric material. However, the variation of refractive index as a function of radius is achieved by radially dependent doping or for a plastic GRIN fiber, is made using two missable polymers with different

refractive indices whose relative concentrations vary radially to produce the desired refractive index profile.

[0006] It would be desirable to provide a simpler method of producing a GRIN fiber with a desired fiber refractive index profile. It would also be desirable to provide a GRIN fiber array having a precision arrangement of GRIN fibers for use in applications such as fiber optic faceplates used as windows for an active device such as a VCSEL emitter or a CCD receiver as well as PD arrays.

[0007] SUMMARY

[0008] Briefly stated, the present invention is directed to a graded index fiber formed from a preform comprising a plurality of fused low index rods with at least one high index rod arranged in a pre-determined pattern which have been drawn and fused.

[0009] In another aspect, the invention provides an array made from such GRIN fibers. A plurality of the GRIN fibers are provided, with each fiber have a center located at a specified position in the array.

[0010] In another aspect, the present invention provides a method of making a graded index fiber. The method includes:

arranging a plurality of low index rods and a plurality of high index rods in a predetermined pattern to form a GRIN fiber preform;

heating the GRIN fiber preform;

drawing and fusing together the GRIN fiber preform of the low index and the high index rods such that relative positions of the low index and high index rods are maintained.

[0011] In another aspect, the present invention provides a method of making a graded index fiber array. The method includes:

arranging a plurality of low index rods and a plurality of high index rods in a predetermined pattern to form a GRIN fiber preform;

heating the GRIN fiber preform;

drawing and fusing together the GRIN fiber preform of the low index and the high index rods such that relative positions of the low index and high index rods are maintained to form a GRIN fiber;

arranging a plurality of the GRIN fibers in a preselected pattern; and

fusing the GRIN fibers together into an array.

[0012] BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The foregoing summary, as well as the following detailed description of the preferred embodiments of the invention will be better understood when read in conjunction with the appended drawings. For the purpose of illustrating the invention, there are shown in the drawings embodiments which are presently preferred. It should be understood, however, that the invention is not limited to the precise arrangements shown.

[0014] Figure 1A is a greatly enlarged cross-sectional view of a GRIN fiber preform for use in making a graded index fiber in accordance with a first preferred embodiment of the present invention.

[0015] Figure 1B is a diagram showing the refractive index distribution of the GRIN fiber formed from the preform of Figure 1A.

[0016] Figure 2A is a greatly enlarged cross-sectional view of a GRIN fiber preform which can be used in a graded index fiber in accordance with a second preferred embodiment of the present invention.

[0017] Figure 2B is a diagram showing the refractive index distribution of the GRIN fiber formed from the preform of Figure 2A.

[0018] Figure 3A is a greatly enlarged cross-sectional view of a GRIN fiber preform for a graded index fiber in accordance with a third preferred embodiment of the present invention having a mode selective distribution.

[0019] Figure 3B is a diagram showing the refractive index distribution for the GRIN fiber formed from the preform of Figure 3A.

[0020] Figure 4 is a greatly enlarged cross-sectional view of a GRIN fiber preform for a graded index fiber in accordance with a fourth preferred embodiment of the invention.

[0021] Figure 5 is a cross-sectional view of a graded index fiber array in accordance with the first preferred embodiment of the invention utilizing the graded index preform of Figure 1.

[0022] Figure 6 is a graded index fiber array having an offset stacking of the fibers.

[0023] Figure 7 is a cross-sectional view of a graded index fiber array in accordance with the present invention having a square pack arrangement.

[0024] DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0025] Certain terminology is used in the following description for convenience only and is not considered limiting. The words "right", "left", "lower" and "upper" designate directions in the drawings to which references made. This terminology includes the words specifically noted above, derivatives thereof and words of similar import. Additionally, the terms "a" and "one" are defined as including one or more of the referenced item unless specifically noted. The term "array" as used herein is intended to include any type of two-dimensional arrangement of fiber ends, such as for a fiber optic faceplate, an image conduit or a flexible image bundle.

[0026] Referring now to Figures 1A and 1B, a schematic diagram of the cross-section of a graded index (GRIN) fiber preform 10 for forming a GRIN fiber is shown. The preform 10 is assembled from multiple rods 11, 12, 13, 14, 15, 16 with different refractive indices. One or more of the low index rods 11, 12, 13, 14 and at least one high index rod 16, are arranged in a pre-determined pattern in order to provide the desired refractive index profile. The preform is heated and drawn in the known manner in order to form a GRIN fiber. Preferably, the GRIN fiber has a diameter of approximately 50 microns. However, the GRIN fiber may be drawn to different final sizes depending on the desired use for the GRIN fiber. It is also possible to provide precision drawing equipment with feedback on the diameter of the drawn fiber in order to form a GRIN fiber having very precise dimensions that are constant to within 0.5 microns along the length of the fiber.

[0027] As shown in Figure 1B, the refractive index profile for the GRIN fiber formed by the preform 10 is a stepped profile which approximates the a curve profile associated with

GRIN fibers known in the prior art. However, through the selection and placement of different rods 11-16, any desired profile can be constructed.

[0028] While the first embodiment of the preform 10 includes rods 11 - 16 having six different indices of refraction, as explained in detail below, all that is required is a plurality of low index rods and at least one high index rod arranged in the pre-determined pattern in order to achieve the desired profile. The refractive indices of the material preferably vary from approximately 1.3 to approximately 1.9. However, higher or lower refractive index materials may be utilized, if desired. One advantage of using only two different indices of refraction to form the perform 10, is that it allows for more efficient manufacturing.

[0029] In the preferred embodiment, the rods 11-16 are made of glass. However, it will be recognized by those skilled in the art from the present disclosure that the rods may be made of a polymeric materials. For example, the rods could be made from polymers such as PMMA and TEFLON®, or other suitable materials.

[0030] Referring now to Figures 2A and 2B, a schematic diagram of a second GRIN fiber preform 20 is shown. The preform 20 comprises a plurality of low index rods 21 and at least one high index rod 22. Preferably, the low index and high index rods 21, 22 are glass. However, those skilled in the art will recognize from the present disclosure that the low index and high index rods may be formed of a polymer. As shown in Figure 2, the low index and high index rods 21, 22 are arranged using a statistical distribution to provide a desired refractive index distribution, as shown in Figure 2B. The refractive index distribution can be adjusted by statistical means utilizing only two types of rods in order to achieve a desired refractive index profile across the preform 20. The low index rods and high index rods are arranged in a pre-determined pattern to form the preform. The preform 20 is heated and drawn in order to fuse the arrangement of low index and high index rods 21, 22 together such that the relative position of the low index and high index rods 21, 22 is maintained to form a GRIN fiber. Preferably, the final GRIN fiber produced from the preform 20 has a diameter of about 125 microns. However, those skilled in the art will recognize from the present disclosure that other diameters may be

formed. As is common in some GRIN fibers, it is preferred that the final GRIN fiber produced from any of the performs of the present invention general preserve the mode of the transmitted signal(s). That is, it is preferred that the GRIN fibers manufactured according to the present invention not scramble the mode of the

[0031]Referring now to Figures 3A and 3B, an alternate arrangement of the low index and high index rods 31, 32 is shown for a GRIN fiber preform 30. This arrangement provides a mode selective distribution with a refractive index profile as shown in Figure 3B. An alternate arrangement of a mode selective GRIN fiber preform 40 is shown in Figure 4.

[0032]Referring now to Figure 5, a plurality of the GRIN fibers, such as those formed from the preforms 10, 20, 30 or 40, or a mixture thereof, are stacked in a desired arrangement and fused together in order to form a graded index fiber array 50. This is done in a manner generally known to those skilled in the art. The plurality of GRIN fibers each have a center located at a specified position, such as a spacing of 125 microns for use in connection with active devices such as CCD receptors, VCSEL emitters and PD arrays and can be used in place of standard fiber optic faceplates as windows. The fused array can be cut into pieces of a desired length and the ends polished to form a faceplate. Alternatively, the fused array can be drawn to a smaller size, if desired, to form an image conduit or flexible image bundle.

[0033]The GRIN fiber array 50 offers the advantage of an increased standoff distance, i.e. the distance between the active device surface and the surface of the faceplate. Faceplates are used in order to transmit an image into a plane on the other face of the array. The preforms may be arranged in various patterns, such as shown in Figures 6 and 7 in order to form arrays having varying numbers of GRIN fibers, with each GRIN fiber being formed by one of the preform 10, 20, 30, 40, as discussed above. While a preferred arrangement includes a 20 x 20 square pack with the GRIN fibers located at a pitch of 125 microns, those skilled in the art recognize that other fiber counts, packing structures and pitches could be used, if desired.

[0034]By using the GRIN fibers of the present invention, new properties, including increased bandwidth, mode control and focusing are provided which were not available in accordance with the prior known GRIN fibers. This is achieved due to the use of the low index and high index rods which are used to form the preform being arranged in a pre-determined pattern in order to provide the desired properties from the GRIN fiber created from the preform.

[0035]While the preferred embodiments of the invention have been described in detail, the invention is not limited to the specific embodiments described above, which should be considered as merely exemplary. Further modifications and extensions of the present invention may be developed, and all such modifications are deemed to be within the scope of the present invention as defined by the appended claims.

* * *